Journal of Petroleum Science and Engineering 171 (2018) 835–842

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Comprehensive investigations into low temperature oxidation of heavy crude oil

Shuai Zhao[a,*], Wanfen Pu[a,b,**], Mikhail A. Varfolomeev[a,b], Chengdong Yuan[a,b], Jizhou Zhang[c], Xiaoqiang Han[c], Yang Yang[c], Xiaoqiang Peng[c], Junxue Wu[c]

[a] *State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, 610500, People's Republic of China*
[b] *Kazan Federal University, Kremlevskaya Str. 18, 420008, Kazan, Russia*
[c] *Research Institute of Experimental and Detection, Petrochina Xinjiang Oilfield Company, Karamay, Xinjiang, 834000, People's Republic of China*

ARTICLE INFO

Keywords:
Low temperature oxidation
Heavy crude oil
Thermal behavior
Kinetics
Coke
Oxidized oil

ABSTRACT

Due to the significance of low temperature oxidation (LTO) process on the subsequent oxidation reactions and oil recovery for in situ combustion (ISC), this work aimed at conducting a series of comprehensive investigations into LTO of heavy crude oil. The LTO behavior of heavy oil was analyzed by static oxidation experiments. Then the alterations in oil characteristics due to LTO were investigated through coke content measurements, flammability tests and scanning electron microscopic (SEM) observations. Additionally, the effect of LTO on thermal behavior and kinetics of heavy oil was researched using thermogravimetry (TG)/differential scanning calorimetry (DSC) technique. The results showed that the temperature played a crucial role in LTO of heavy oil. Almost no coke was deposited at 80 °C. The amount of coke deposition at 160 °C averaged 0.346 g coke/g oil, which was roughly 4.2 times higher than that at 120 °C. The oxidized oil at 160 °C possessed the most superior flammability at ambient temperature and atmospheric pressure in comparison to that at 80 and 120 °C. The surface morphologies of oxidized oil at 160 °C and its formed coke were quite rough, which boosted the subsequent combustion reactions. The results of TG/DSC unravelled that the oxidized oils were subjected to higher mass loss and exothermic effect at the fuel deposition (FD) and high temperature oxidation (HTO) stages as compared to crude oil. After the static LTO, the activation energy in the LTO and FD stages for heavy oil was increased, while that in the HTO stage was reduced. Compared with crude oil and oxidized oils, the coke deposited during the static LTO presented the highest thermal release and reaction activity in the HTO interval. This paper can provide some new insights regarding LTO mechanisms of heavy oil to rich the ISC technology.

1. Introduction

With the sustainable energy demand growth coupled with the depletion of conventional light and medium oilfields, the increasing attention has been put on the heavy oil reservoirs with a huge amount of reserves (Larter et al., 2008). However, it is still a challenge for heavy oil being produced economically and efficiently due to its high viscosity and poor flow property in porous media. Various thermal recovery technologies, including ISC, steam-assisted gravity drainage (SAGD), steam flooding, in situ electrical heaters etc., have been proven to be promising strategies regarding the exploitation of heavy oil reservoirs (Pu et al., 2015a). For ISC, oxygen-enriched gas or air is firstly injected to the target zone with the aim of producing a variety of oxidation reactions between crude oil and air in place, followed by the generation of some oxygenated compounds and coke. A combustion front induced by self-ignition or an external burner will propagate downstream slowly by the sequent air flow. Distinctive thermal effects along with miscible and/or immiscible flue gas flooding boost the production of heavy oils (Kovscek et al., 2013; Zhao et al., 2016).

As reported by most researchers, the ISC process can generally be categorized into three main stages, that is, LTO, FD and HTO (Huang and Sheng, 2017; Kok and Gundogar, 2013; Li et al., 2017b). With regard to heavy oil reservoirs, the LTO reactions are notably vital since the LTO products have significant influences on the sustainability of combustion front. Nevertheless, if an excess of LTO products with viscosities much greater than that of the crude oil are formed, they will

* Corresponding author.
** Corresponding author. State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, 610500, People's Republic of China.
E-mail addresses: zs77816@163.com (S. Zhao), puwanfenswpu@163.com (W. Pu).

https://doi.org/10.1016/j.petrol.2018.08.027
Received 14 June 2018; Received in revised form 25 July 2018; Accepted 9 August 2018
Available online 10 August 2018